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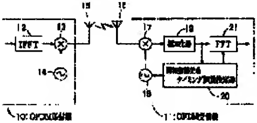
(54) OFDM SIGNAL RECEIVER, OFDM SIGNAL COMMUNICATION SYSTEM AND ITS COMMUNICATION CONTROL METHOD



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SOLUTION: This system is provided with an orthogonal frequency division multiplex(OFDM) transmitter 10 and an OFDM receiver 11. The OFDM receiver 11 is provided with an antenna 16 that receives an OFDM signal from the OFDM transmitter 10, a frequency converter 17 that converts a frequency of a received RF signal into a frequency of a base band signal, a local oscillator 18 that supplies a local oscillation signal to the frequency converter 17, a sampling unit 19 that samples the base band signal, a frequency error and timing error estimate device 20 that detects an error of a carrier frequency and a timing error, and a fast Fourier transform(FFT) unit 21 that converts a time- domain signal outputted from the sampling unit 19 into a frequency-domain signal. The frequency error and timing error estimate device 20 estimates an error of the carrier frequency of the OFDM signal and an error in the sampling timing and uses the estimate result to control the local oscillator 18 and the FFT 21.

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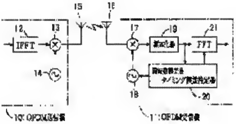

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PROBLEM TO BE SOLVED: To attain data transmission with high reliability without increasing a circuit scale.

SOLUTION: This system is provided with an orthogonal frequency division multiplex(OFDM) transmitter 10 and an OFDM receiver 11. The OFDM receiver 11 is provided with an antenna 16 that receives an OFDM signal from the OFDM transmitter 10, a frequency converter 17 that converts a frequency of a received RF signal into a frequency of a base band signal, a local oscillator 18 that supplies a local oscillation signal to the frequency converter 17, a sampling unit 19 that samples the base band signal, a frequency error and timing error estimate device 20 that detects an error of a carrier frequency and a timing error, and a fast Fourier transform(FFT) unit 21 that converts a time- domain signal outputted from the sampling unit 19 into a frequency-domain signal. The frequency error and timing error estimate device 20 estimates an error of the carrier frequency of the OFDM signal and an error in the sampling timing and uses the estimate result to control the local oscillator 18 and the FFT 21.

CLAIMS

[Claim(s)]

[Claim 1]A reception means which receives with an antenna an OFDM (orthogonal frequency division multiplex) signal with which a pilot signal which consists of a predetermined known signal series was inserted.

A local oscillator which generates a reproduced carrier signal which is a reference signal for restoring to said OFDM signal.

A frequency converter which changes said OFDM signal into a baseband signal based on said reproduced carrier signal, and an FFT operation means which performs FFT computation based on said baseband signal, and generates received data of a frequency domain.

A sampling means which is the OFDM signal receiving set provided with the above, and samples said baseband signal, Two or more complex correlation arithmetic means which perform complex correlation operation between a reference signal with which a frequency offset which is different to said pilot signal, respectively was set up, and said pilot signal, and ask for a correlation output, Based on an obtained correlation output, by each of two or more of said complex correlation arithmetic means, a frequency error of said reproduced carrier signal and a carrier signal of said OFDM signal, Have an error estimation means to presume a timing error at the time of said FFT operation means calculating, and said local oscillator, Controlling frequency of said reproduced carrier signal based on said frequency error, said FFT operation means determines an FFT window based on said timing error.

[Claim 2]Have the 1st maximum search means that searches the maximum of a correlation output outputted from each of two or more of said complex correlation arithmetic means, and said error estimation means, The OFDM signal receiving set according to claim 1 characterized by presuming said frequency error and said timing error based on a frequency offset corresponding to said complex correlation arithmetic means which outputted the maximum searched with said 1st maximum search means.

[Claim 3]Have the 2nd maximum search means that searches the maximum of a correlation output of said complex correlation arithmetic means which outputted the maximum searched with said 1st maximum search means, and said error estimation means, The OFDM signal receiving set according to claim 2 characterized by presuming said frequency error and said timing error based on the maximum searched with said 2nd maximum search means.

[Claim 4]The OFDM signal receiving set comprising according to any one of claims 1 to 3:

The number of shift stages of each of two or more of said complex correlation arithmetic means as which a baseband signal sampled by said sampling means is inputted is the 1st signal shifting means of L (L is two or more integers) stage.

An adding means which adds each multiplication result by M complex multiplication means which carry out the multiplication of an output and said reference signal of M (M is two or more integers and is M<L) stage selected from each stages of said 1st signal shifting means, respectively, and said M complex multiplication means, and calculates said correlation output.

[Claim 5]An OFDM signal receiving set comprising:

A delay means delayed in a baseband signal which said at least two pilot signals are included in said OFDM signal, and was sampled by said sampling means.

The number of shift stages as which a baseband signal sampled by said sampling means is inputted is the 2nd signal shifting means of L (L is two or more integers) stage.

The number of shift stages as which said baseband signal delayed by said delay means is inputted is the 3rd signal shifting means of L (L is two or more integers).

An adding means adding each multiplication result by M multiplication means which carry out the multiplication of an output of M (M is two or more integers and is M<L) stage selected from each stages of said 2nd signal shifting means, and the output of said M stage selected from each stages of said 3rd signal shifting means, and said M multiplication means.

[Claim 6]A reception means which receives with an antenna an OFDM (orthogonal frequency division multiplex) signal with which a pilot signal which consists of a predetermined known signal series was inserted.

A local oscillator which generates a reproduced carrier signal which is a reference signal for restoring to said OFDM signal.

A frequency converter which changes said OFDM signal into a baseband signal based on said reproduced carrier signal, and an FFT operation means which performs FFT computation based on said baseband signal, and generates received data of a frequency domain.

It has a transmitting means which transmits an OFDM signal with which said pilot signal of a round series which is the OFDM signal communications system provided with the above, and is patrolled with a predetermined cycle was inserted towards said reception means via an antenna.

[Claim 7]The OFDM signal communications system according to claim 6, wherein said transmitting means constitutes said pilot signal using said round series by which equipartition of the electric power is carried out to a representative vector in a segment of time which constitutes said pilot signal.

[Claim 8]A reception means which receives with an antenna an OFDM (orthogonal frequency division multiplex) signal characterized by comprising the following with which a pilot signal which consists of a predetermined known signal series was inserted, A local oscillator which generates a reproduced carrier signal which is a reference signal for restoring to said OFDM signal, A communication control method of an OFDM signal communications system provided with a frequency converter which changes said OFDM signal into a baseband signal based on said reproduced carrier signal, and an FFT operation means which performs FFT computation based on said baseband signal, and generates received data of a frequency domain.

The 1st step that samples said baseband signal.

The 2nd step that performs complex correlation operation between a reference signal with which a frequency offset which is different to said pilot signal, respectively was set up, and said pilot signal, and asks for a correlation output.

The 3rd step that presumes a frequency error of said reproduced carrier signal and a carrier signal of said OFDM signal based on two or more correlation outputs obtained at said 2nd step.

The 4th step that controls frequency of said reproduced carrier signal which said local oscillator generates based on said frequency error presumed at said 4th step.

[Claim 9]Based on two or more correlation outputs obtained at said 2nd step, presume said 3rd step, and a timing error at the time of said FFT operation means calculating said FFT operation means, A communication control method of the OFDM signal communications system according to claim 8 determining an FFT window based on said timing error.

DETAILED DESCRIPTION

[Detailed Description of the Invention]

[0001]

[Field of the Invention]This invention relates to the OFDM signal receiving set which transmits and receives data using the OFDM (Orthogonal Frequency Division Multiplexing) signal which comprises two or more subcarrier (career) signals by which orthogonal arrangement was carried out.

[0002]

[Description of the Prior Art]In recent years, development of the OFDM signal communications system which transmits the digital information of a sound, an image or data, etc., etc. is furthered, and digital communication is becoming in use also in mobiles, such as a cellular phone.

[0003]It is necessary to take into consideration the influence of two or more reflected waves (multipass) depended on buildings, such as a building, or other reflecting objects in mobile communications. That is, the electric wave from two or more transmitting stations reaches at a receiving point. The phenomenon of such a multipass becomes the big cause of making a signal producing distortion and degrading receiving quality.

[0004]The correspondence to various demand quality is searched for in the OFDM signal communications system treating multimedia information etc. For example, in the multimedia digital communication using a small Personal Digital Assistant, a reliable signal transmission is needed, having the convenience of the mobile communications connected to a net etc. from arbitrary points.

[0005]Not only in mobile communications but in digital communication, in order to restore the information transmitted from a transmitter, it is necessary to establish frequency synchronization and a timing synchronization. In particular, since a receive state is changed, synchronous processing is indispensable, but mobile communications take a certain amount of time, in order to take a synchronization. After the synchronization has separated, since restoration of information becomes impossible, frequency synchronization and a timing synchronization high-speed also for recovery when a synchronization separates are needed.

[0006]In the OFDM signal communications system treating multimedia information etc., since the signal transmitted occurs burstily, it is suitable for packet communication. In packet communication, it is not a fixed cycle like time division multiple access (TDMA), and a packet is transmitted at random. For this reason, it is necessary to establish a synchronization for every packet, and a synchronization must be established in short time. From a viewpoint of a miniaturization, since use of a high precision oscillator is difficult, it is necessary to apply the highly efficient carrier frequency synchronizing method in the Personal Digital Assistant dealing with multimedia information.

[0007]By the way, effective methods of reducing the influence of the delayed wave in a multipass propagation path include OFDM (Orthogonal Frequency Division Multiplexing). OFDM is a method which modulates independently the subcarrier which divides transmitted data, generates a low speed plurality digital signal, and is in orthogonality relation by the two or more signals. Compared with a single career modulation method, the influence of a delayed wave can be reduced by being able to make signal-transmission speed low and providing a guard interval still more peculiar to OFDM by the parallel transmission using a multi-carrier.

[0008]The outline of an OFDM system is explained below.

[0009]Drawing 21 is a block diagram showing the composition of the OFDM modulation device used for the transmitting side. Send data is inputted into an OFDM modulation device. This send data is supplied to the serial/parallel-conversion part 201, and is changed into the data which consists of two or more low speed transmission symbols. That is, transmitted data are divided and a low speed plurality digital signal is generated. These parallel data are supplied to the reverse Fast Fourier Transform (IFFT) part 202.

[0010]Parallel data are assigned to each subcarrier which constitutes OFDM, and are mapped in a frequency domain. Here, the abnormal conditions of BPSK, QPSK, 16QAM, 64QAM, etc. are performed to each subcarrier. Mapping data is changed into the send data of a segment of time from the send data of a frequency domain by performing an IFFT operation. The multi-carrier modulating signal with which two or more subcarriers which have a relation which intersects perpendicularly mutually by this were modulated independently, respectively is generated. The output of IFFT part 202 is supplied to the guard-intervals adjunct 203.

[0011]The guard-intervals adjunct 203 adds a copy to the anterior part of an effective symbol period for every transmission symbol by making the rear of the valid symbol of transmission data into guard intervals, as shown in drawing 22. The baseband signal acquired by this guard-intervals adjunct is supplied to the quadrature modulation part 204.

[0012]As opposed to the baseband OFDM signal with which the quadrature modulation part 204 is supplied from the guard-intervals adjunct 203, Using the carrier signal supplied from the local oscillator 205 of an OFDM modulation device, quadrature modulation is performed and frequency conversion is carried out to an intermediate frequency (IF) signal or a radio frequency (RF) signal. That is, after a quadrature modulation part carries out frequency conversion of the baseband signal to desired transmission frequency bandwidth, it is outputted to a transmission line.

[0013]Drawing 23 is a block diagram showing the composition of the OFDM demodulator used for a receiver. The OFDM signal generated by the OFDM modulation device of drawing 21 is inputted into an OFDM demodulator via a predetermined transmission line.

[0014]The OFDM reception signal inputted into this OFDM demodulator is supplied to the orthogonal demodulation part 211. To an OFDM reception signal, the orthogonal demodulation part 211 performs orthogonal demodulation using the carrier signal supplied from the local oscillator 212 of an OFDM demodulator, carries out frequency conversion to a baseband signal from an RF signal or an IF signal, and acquires a baseband OFDM signal. This OFDM signal is supplied to the guard-intervals removing part 213.

[0015]The guard-intervals removing part 213 removes the signal added by the guard-intervals adjunct 203 of the OFDM modulation device according to the timing signal supplied from the symbol timing synchronizer which is not illustrated. The signal acquired by this guard-intervals removing part 203 is supplied to the Fast Fourier Transform (FFT) part 214.

[0016]FFT section 214 is changed into the received data of a frequency domain by carrying out FFT of the received data of a segment of time inputted. Furthermore in a frequency domain, it is demapped and parallel data are generated for every subcarrier. It means that the recovery to the abnormal conditions of BPSK, QPSK, 16QAM, 64QAM, etc. which were given to each subcarrier was made here. The parallel data obtained by FFT section 214 are supplied to the parallel/serial-conversion part 215, and are outputted as received data.

[0017]As explained above, the OFDM demodulator needs to establish a carrier frequency synchronization and a timing frequency synchronization, in order to restore the information transmitted from an OFDM modulation device.

[0018]Since a subcarrier interval is narrow and orthogonal arrangement of each subcarrier is carried out in OFDM, When the carrier frequency supplied from the local oscillator 212 of an OFDM demodulator and the carrier frequency of the OFDM modulation device have shifted (i.e., when a frequency offset exists), the orthogonality between subcarriers collapses and a receiving characteristic deteriorates remarkably. Therefore, in OFDM, carrier frequency synchronous establishment is very important.

[0019]The frequency synchronization method of OFDM is shown in "examination about the synchronizing systems of the OFDM modulation method for high-speed wireless LAN", etc. of Institute of Electronics, Information and Communication Engineers technical research report RCS97-210 (1998-01).

[0020]The method of synchronizing OFDM is classified into what is depended on processing in a frequency domain, and the thing to depend on processing by a segment of time. The synchronizing method written in the above-mentioned report is based on processing by a segment of time. In this method, using two OFDM symbols, the same signal is arranged to those two pilot symbols, and a gap of a carrier frequency and a gap of timing are presumed by both correlation operation.

[0021]Before transmitting a data symbol, the technique of transmitting separately the start symbol which determines an initial phase, and presuming a frequency error is also known. However, in this kind of frequency error estimation method, since it is necessary to transmit the pilot symbol of two or more symbols, there is a problem that transmission efficiency will fall.

[0022]Although it is possible to serve both as this start symbol and pilot symbol for improvement in transmission efficiency, in order for the point that the pilot symbol of two or more symbols is needed also in this case for a synchronization not to change, there is a problem that transmission efficiency will fall.

[0023]On the other hand, the offset presuming method of the carrier frequency using two or more complex correlators is indicated by Institute of Electronics, Information and Communication Engineers paper magazine B-II Vol. J75-B-II, No.12, and p884-895 (December, 1992). Frequency-offset detection / removal method shown in drawing 24 is proposed by this literature. This literature is aimed

at the single career modulation method using the training signal added to a TDMA slot.
The same reference frame sequence is set to the formed correlator, and the frequency of the input signal inputted into correlator is changed to it.

[0024]As for the increase in circuit structure, since it leads to the increase in a manufacturing cost, stopping low as much as possible is [circuit structure] desirable [in order to accelerate an initial synchronization, increase of a certain amount of circuit structure is not avoided, but]. However, since two or more complex correlators are needed in the case of the above-mentioned literature, there is a problem that circuit structure becomes large.

[0025]This invention is made in view of such a point, and the purpose is to provide the OFDM signal receiving set and OFDM signal communications system which can perform reliable data communications, without increasing circuit structure.

[0026]

[Means for Solving the Problem]In order to solve a technical problem mentioned above, an invention of claim 1, A reception means which receives with an antenna an OFDM (orthogonal frequency division multiplex) signal with which a pilot signal which consists of a predetermined known signal series was inserted, A local oscillator which generates a reproduced carrier signal which is a reference signal for restoring to said OFDM signal, A frequency converter which changes said OFDM signal into a baseband signal based on said reproduced carrier signal, An FFT operation means which performs FFT computation based on said baseband signal, and generates received data of a frequency domain, A sampling means which is a ******** OFDM signal receiving set and samples said baseband signal, Two or more complex correlation arithmetic means which perform complex correlation operation between a reference signal with which a frequency offset which is different to said pilot signal, respectively was set up, and said pilot signal, and ask for a correlation output, Based on an obtained correlation output, by each of two or more of said complex correlation arithmetic means, a frequency error of said reproduced carrier signal and a carrier signal of said OFDM signal, Have an error estimation means to presume a timing error at the time of said FFT operation means calculating, and said local oscillator controls frequency of said reproduced carrier signal based on said frequency error, Said FFT operation means determines an FFT window based on said timing error.

[0027]Perform complex correlation operation between a reference signal and a pilot signal which set up a frequency offset which is different to a pilot signal, respectively in an invention of claim 1, and it asks for a correlation output, Since a timing error at the time of a frequency error and an FFT operation means of a reproduced carrier signal and a carrier signal of an OFDM signal calculating is searched for based on these correlation outputs, a frequency error and a timing error can be calculated with simply and sufficient accuracy.

[0028]In an invention of claim 2, since a frequency error and a timing error are presumed based on a frequency offset corresponding to a complex correlation arithmetic means which outputted the maximum of a correlation output, a frequency error and a timing error can be calculated with sufficient accuracy.

[0029]Since the maximum of a correlation output which a complex correlation arithmetic means which outputted the maximum of a correlation output outputs is further searched with an invention of claim 3 and a frequency error and a timing error are presumed based on the searched maximum, a frequency error and a timing error can be calculated with still more sufficient accuracy.

[0030]In an invention of claim 4, since a complex multiplication means is not connected to each stage of the 1st shifting means but a complex multiplication means is connected only to some stages, circuit structure is reducible.

[0031]In order to take correlation between a baseband signal and its signal delay, it becomes unnecessary to establish a reference signal in an invention of claim 5.

[0032]In an invention of claim 6, since an OFDM signal with which a pilot signal of a round series patrolled with a predetermined cycle was inserted is transmitted, a complex multiplier can be arranged at equal intervals.

[0033]Since electric power constitutes a pilot signal from an invention of claim 7 using a round series by which equidistribution is carried out in a representative vector, power efficiency becomes good.

[0034]Perform complex correlation operation between a reference signal and a pilot signal which set up a frequency offset which is different to a pilot signal, respectively in an invention of claim 8, and it asks for a correlation output, Since a frequency error of a reproduced carrier signal and a carrier signal of an OFDM signal is searched for based on these correlation outputs, a frequency error can be calculated with simply and sufficient accuracy.

[0035]In an invention of claim 9, in order to also presume a timing error at the time of an FFT operation means calculating based on a correlation output, accuracy of FFT computation improves.

[0036]

[Embodiment of the Invention]Hereafter, the OFDM signal receiving set and OFDM signal communications system concerning this invention are explained concretely, referring to drawings.

[0037]Drawing 1 is a block diagram of one embodiment of the OFDM signal communications system provided with the OFDM signal receiving set concerning this invention. The OFDM signal communications system of a graphic display transmits and receives the OFDM signal mentioned above, and comprises OFDM transmitter 10 and OFDM receiver 11. A part of component of the OFDM signal communications system is shown in drawing 1.

[0038]OFDM transmitter (transmitting means) 10 is provided with the following.

Reverse fast Fourier transformation equipment (IFFT) 12 which changes into the signal of a segment of time the transmission signal mapped in the frequency domain.

The frequency converter 13 which carries out frequency conversion of the signal of a segment of time to an RF signal.

The local oscillator 14 which supplies the carrier signal (local oscillation signal) of a sine wave to the frequency converter 13.

The antenna 15 emitted to a propagation path by making an RF signal into an electric wave.

[0039]OFDM receiver 11 is provided with the following.
The antenna (reception means) 16 which receives the OFDM signal which was transmitted from the transmitter 10 and reached through wireless propagation paths.
The frequency converter 17 which carries out frequency conversion of the RF signal received with the antenna 16 to a baseband signal.
The local oscillator 18 which supplies the local oscillation signal of a sine wave to the frequency converter 17.
The sampling machine (sampling means) 19 which samples the received baseband signal, The frequency error & timing error estimation machine (error estimation means) 20 which detects a frequency offset and timing offset using the output signal of the sampling machine 19, and the fast Fourier transformation equipment (FFT, FFT operation means) 21 which changes into a frequency domain signal the segment-of-time signal which the sampling machine 19 outputs.

[0040]In drawing 1, the guard-intervals adjunct and guard-intervals removing part which were explained by drawing 22 are omitted for simplification.
[0041]Drawing 2 is a figure showing the data configuration of the burst frame of the OFDM signal transmitted from OFDM transmitter 10. The pilot symbol (pilot signal) to which a known signal series is transmitted is contained in the burst frame. In the OFDM signal communications system treating multimedia information, the signal transmitted occurs burstily. For this reason, it is necessary to establish a synchronization for every burst frame. In drawing 2, although the pilot symbol of one symbol is illustrated, the pilot symbol (pilot signal) of one or more symbols may be added.
[0042]In order to perform synchronous detection to an OFDM signal, it is necessary to transmit a known signal so that a receiver can grasp an absolute phase. A start symbol must be transmitted in order to perform differential detection. According to this embodiment, the pilot symbol of one or more symbols is added as a burst frame

structure of an OFDM signal. For this reason, it becomes possible to serve as the pilot symbol for frequency synchronization, and the start symbol for the known signal for synchronous detection, or differential detection, and degradation of transmission efficiency can be prevented.

[0043]The frequency error & timing error estimation machine 20 shown in drawing 1 detects a frequency error and a timing error using the signal which the sampling machine 19 outputs with the signal acquired by the slide correlation operation of the signal and input signal which are transmitted in a pilot symbol.

[0044]The carrier frequency error information outputted from the frequency error & timing error estimation machine 20 is supplied to the local oscillator 18. The local oscillator 18 changes the oscillating frequency of a reproduced carrier signal (local oscillation signal) based on the inputted carrier frequency error information. The timing error information outputted from the frequency error & timing error estimation machine 20 is supplied to FFT21. FFT21 determines an FFT window based on timing error information.

[0045]Thus, in this embodiment, using the signal of the segment of time in the pilot symbol in an OFDM reception signal, presumption of a gap of a carrier frequency and presumption of a gap of the timing of a sampling are performed, and synchronous acquisition of a carrier frequency and synchronous acquisition of sampling timing are performed. The details of operation of this embodiment are mentioned later.

[0046]Drawing 3 is a block diagram showing the internal configuration of the frequency error & timing error estimation machine 20 shown in drawing 1. As shown in drawing 3, the frequency error & timing error estimation machine 20 is provided with the following.

The shift register (1st signal shifting means) 30 which shifts the signal which the sampling machine 19 outputted with the sampling clocks into which it is inputted by the sampling machine 19.

Two or more complex correlators (complex correlation arithmetic means) 31-33.

The maximum primary detecting element (1st maximum search means) 34 which detects the maximum (the maximum signal of a frequency error, and the maximum signal of a correlation output) of the signal which the complex correlators 31-33 outputted.

The maximum primary detecting element (2nd maximum search means) 36 which detects the maximum of the output (signal which shifted the output of the maximum primary detecting element 34) of the shift register 35 which shifts the signal which the maximum primary detecting element 34 outputted with the sampling clocks into which it is inputted by the sampling machine 19, and the shift register 35.

[0047]The frequency error & timing error estimation machine 20 has two or more complex correlators 31-33, and 37-39 are set to each complex correlators 31-33 for a reference frame sequence different, respectively. Each complex correlators 31-33 are provided with the following.

The complex multiplier (complex multiplication means) 40 which carries out the multiplication of the output signal and reference frame sequence of each stage of the shift register 30.

The adding machine 41 adding the output of the complex multiplier 40.

The reference frame sequences 37-39 set as the complex correlators 31-33 are the signals which gave a different frequency offset to the signal transmitted in a pilot symbol. The details of a reference frame sequence are mentioned later.

[0048]Next, the detecting method of a gap of sampling timing and a gap of a carrier frequency is explained. In order to simplify explanation, the OFDM signal in the equivalent reduction which removed carrier signal components is dealt with. The OFDM sending signal s (t) in equivalent reduction can be expressed with (1) type.

[0049]

[Equation 1]

$$s(t)=\left(\frac{1}{N_s}\sum_{v=0}^{N-1} d_{uv}\cdot \chi_{uv}(t)\right)\cdot \exp\left(\Delta\omega o\frac{1}{T_s}t+\Delta\theta o\right) \quad \cdots(1)$$

(1) As for the number of subcarriers with which Ns constitutes an OFDM signal, and N, in a formula, a symbol number and v of the point size of FFT and u are the

numbers of subcarriers. x_{uv} is numerals which transmit and, in the case of QPSK, it is expressed with (2) types.

[0050]

[Equation 2]

$$d_{uv} \in \{A_{uv} \cdot \exp\ j\frac{2\pi k}{K},\quad (k=0,\ 1,\ \cdots 3)\} \qquad \cdots(2)$$

(2) in a formula, A_{uv} is amplitude -- a null -- in the case of a subcarrier, it is $A_{uv}=0$. In (1) type, g_{uv} (t) is the isolated pulse response of OFDM in the u-th symbol and the v-th symbol, and is expressed with (3) types.

[0051]

[Equation 3]

$$\chi_{uv}(t)=\exp\{j2\pi f_v(t-Tg-u\cdot T)\cdot \Pi(t-uT)) \qquad \cdots(3)$$

(3) In a formula, as for the v-th subcarrier frequency and Tg, guard interval length and Ts of fv are effective symbol length and T=Tg+Ts, and II (t) is expressed with (4) types.

[0052]

[Equation 4]

$$\Pi(t)=\begin{cases} 1 & \text{if } 0 \leqq t < T \\ 0 & \text{otherwise} \end{cases} \qquad \cdots(4)$$

(3) The input signal r (t) in a formula is expressed with (5) types supposing wireless propagation paths are non-strains.

[0053]

[Equation 5]

$$r(t)=s(t)\ \cdot \exp\left(2\pi\Delta f\frac{1}{Ts}t+\Delta\theta o\right)+n(t) \qquad \cdots(5)$$

(5) As for deltaf, in a formula, phase offset and n (t) of a frequency offset and deltatheta_0 are complex white Gaussian random noises.

[0054]When the input signal r (t) is sampled with N sample per symbol, a sampling power range system sequence is set to r_k=r (t_k). However, it is t_k=(k/Ts)

+Tg+deltatau, k= 0, 1, --, N-1, and deltatau is timing offset.

[0055]Since the signal transmitted in a pilot symbol is a known signal series, the time waveform of the pilot symbol received with OFDM receiver 11 is known. Therefore, OFDM receiver 11 can acquire a correlation value sequence by performing correlation operation of the time waveform and input signal which were prepared beforehand. For example, in drawing 3, the signal sequence outputted from the complex correlators 31-33 hits this correlation value sequence.

[0056]Drawing 4 shows an example of a correlation value sequence outputted from the complex correlator 31. This correlation value sequence is equivalent to an impulse response of wireless propagation paths. That is, a delay profile is expressed. When a propagation path can make a model with a two pass, two correlation peaks can be observed.

[0057]Correlation operation of a signal which received a signal transmitted in a pilot symbol, and a signal beforehand prepared with a receiver is equivalent to autocorrelation arithmetic. A series acquired by this autocorrelation arithmetic is shown in drawing 5. A correlation peak as shown in drawing 5 appears for a series acquired by autocorrelation arithmetic. Portions other than a correlation peak serve as a correlation side lobe. It depends for the characteristic of a correlation side lobe on the autocorrelation characteristic of a time waveform of an OFDM signal.

[0058]A correlation peak of drawing 5 shows a position of a known signal with a good autocorrelation characteristic included in an input signal, and can establish a synchronization of a burst frame by detecting this position.

[0059]In a peak search using a known signal with a good autocorrelation characteristic included in an input signal, if there is a frequency error, a signal level which the complex correlators 31-33 output will fall, and the synchronous characteristic will deteriorate. However, in an OFDM signal communications system in this embodiment. Since it is set as two or more complex correlators 31-33 to a signal transmitted in a pilot symbol by making into a reference frame sequence a signal which gave a frequency offset different, respectively as shown in drawing 3, By taking correlation corresponding to two or more frequency offsets, a fall of a correlation output level under influence of a frequency error can be prevented, and degradation of the synchronous characteristic can be suppressed.

[0060]Reference frame sequence d_k which gave frequency-offset f_k to a signal transmitted in a pilot symbol is expressed with (6) types.

[0061]

[Equation 6]

$$dk = uk \cdot \exp\left(j 2 \pi f k \frac{k}{n}\right) \qquad \cdots (6)$$

(6) In a formula, u_k is a discrete value of a sending signal and is u_k=s (k/N). However, N is a point size of FFT.

[0062]The frequency response a of a reference frame sequence which gave frequency-offset f_k to a signal transmitted in a pilot symbol, and a correlation output of an input signal (deltaf) is expressed with (7) types.

[0063]

[Equation 7]

$$a(\Delta f) = \sum_{j=0}^{N-1} ri \cdot di^{*} \qquad \cdots (7)$$

(7) In a formula, di^* is a complex conjugate of di. Here, if it assumes that noise, a timing gap of a sampling, and the influence of phase offset can be disregarded, (7) types will change like (8) types.

[0064]

[Equation 8]

$$a(\Delta f) = \sum_{i=0}^{N-1} |u(i)|^{2} \cdot \exp\left\{j 2 \pi (\Delta f - f k) \frac{i}{N}\right\} \qquad \cdots (8)$$

(8) A formula shows depending for the frequency response of a correlation output on the signal series transmitted in a pilot symbol.

[0065](8) In the formula, $|u(i)|^2$ expresses the size of a sending-signal series and exp (j2pi (deltaf-f_k) and i/N) expresses the gap of frequency with reference frame sequence d_k. The vector showing a gap of frequency rotates according to a series number, and it depends for a rotation on a gap of frequency. That is, direction rotates the series which exp (j2pi (deltaf-f_k) and i/N) expresses according to a series number, and length is a vector which is a size of a sending-signal series.

[0066]Drawing 6 is a figure showing a reference frame sequence which gave frequency-offset deltaf to a frequency response shown in (8) types, i.e., a signal transmitted in a pilot symbol, and an example of a frequency response of size |a(deltaf) |^2 of a correlation output of an input signal. However, in drawing 6, f_k is 0. Drawing 6 shows that a correlation value becomes the maximum, when a frequency offset is 0.

[0067]Namely, when a reference frame sequence which has a frequency offset different, respectively is set as two or more complex correlators 31-33 shown in drawing 3, By a frequency offset corresponding to complex correlator which searched the maximum of a correlation output absolute value of a reference frame sequence and an input signal which are outputted from each complex correlators 31-33, and outputted the maximum. A gap with a carrier frequency of an OFDM sending signal and a carrier frequency of an OFDM reception signal is detectable.

[0068]The maximum primary detecting element 34 in drawing 3 performs a search procedure mentioned above, and outputs an error signal of a carrier frequency, and a maximum signal of a correlation output.

[0069]Drawing 6 shows an example of a frequency response of size |a(deltaf) |^2 of a correlation output of the two reference frame sequences A and B and input signals which differ in a known signal series transmitted in a pilot symbol. Drawing 6 shows depending for a frequency response of size |a(deltaf) |^2 of a correlation output of a reference frame sequence and an input signal on a known signal series.

[0070]In drawing 3, the shift register 35 connected to the maximum primary detecting element 34 shifts in order a maximum signal of a correlation output which the maximum primary detecting element 34 outputted, and the maximum primary detecting element 36 detects the maximum out of an output of each stage of the shift register 35. This maximum shows an autocorrelation peak of a series acquired by autocorrelation arithmetic mentioned above, and this peak position shows reference timing of a burst frame of a signal received through wireless propagation paths.

[0071]The maximum primary detecting element 36 outputs a timing error signal which is an error of reference timing of a detected burst frame, and timing of OFDM receiver 11. The maximum primary detecting element 36 detects the maximum of a correlation output which complex correlator which outputted the maximum of a correlation output detected in the maximum primary detecting element 34 outputted, and outputs a frequency offset corresponding to timing to which the maximum of a correlation output is outputted as a frequency error signal.

[0072]Frequency offset quantity obtained here is a discrete value depending on the number of complex correlator. Therefore, accuracy of a frequency error signal can be raised by performing interpolating calculation.

[0073]By the above composition, it becomes detectable [a sampling timing error and an error of a carrier frequency], and an OFDM signal communications system in which a reliable signal transmission is possible can be realized.

[0074]As mentioned above, since a signal transmitted occurs burstily, with an OFDM signal communications system treating multimedia information etc., it is necessary to establish a synchronization for every burst frame for a short time. As for increase of circuit structure, although increase of a certain amount of circuit structure is not avoided for a high-speed initial synchronization, since it leads to a rise of a manufacturing cost, it is desirable [circuit structure] to make it as small as possible. That is, it becomes an important technical technical problem what complex slide correlator whose rate of occupying under the whole circuit burden is comparatively large is considered as simple composition.

[0075]Then, the technique of reducing circuit structure of complex correlator shown in drawing 3 is explained below. A technique explained below pays its attention to correlation operation with a reference frame sequence which gave a different frequency offset to a signal transmitted in a pilot symbol.

[0076]As mentioned above, (8) types mentioned above can express the correlation output a of a reference frame sequence and an input signal which gave frequency-offset deltaf to a signal transmitted in a pilot symbol (deltaf). In order to simplify explanation, in (8) types, it is assumed that a gap of noise and sampling timing and influence of phase offset can be disregarded.

[0077]As a vector showing a gap of frequency is shown in drawing 7, it rotates according to a series number of a signal series of a pilot signal, and depends for a rotation on a gap of frequency. This vector is turned at the time of deltaf=1. That is, direction rotates a series which exp (j2pi(deltaf-fk) i/N) expresses according to a series number, and length is a vector which is a size of a sending-signal series.

[0078]Here, the feature of $|u(i)|^2$ and exp (-j2pi(deltaf-fk) i/N) is considered. Change of size $|u(i)|^2$ of a sending-signal series explains using a small example so that it may be easy to understand change of a vector locus.

[0079]An example of a vector locus is shown in drawing 8 and drawing 9. It is several Ns=4 of a subcarrier which constitutes the point size N= 64 of FFT, and an OFDM signal, and drawing 8 is deltaf=0.25 and drawing 9 is deltaf=0.5.

[0080]It can be understood that that a vector locus becomes like drawing 8 and drawing 9 observes size $|u(i)|^2$ of a sending-signal series.

[0081]Drawing 10 is a figure showing size $|u(i)|^2$ of a sending-signal series corresponding to drawing 8 and drawing 9. A horizontal axis of drawing 10 is sample-number i, and a vertical axis is $|u(i)|^2$.

[0082]From drawing 8 - drawing 10, direction rotates according to a series number and the series which $|u(i)|^2$ and exp (-j2pi(deltaf-fk) i/N) express can check that length is a vector which is a size of a sending-signal series. The correlation output a (deltaf) shown by (8) formulas is computed from a vector sum of these loci.

[0083]Here, its attention is paid to distribution of a vector locus shown in drawing 8 and drawing 9. Drawing 8 and drawing 9 show that many distribution exists near the starting point. Distribution of size $|u(i)|^2$ of a sending-signal series has [this] the zero high neighborhood, distribution to which it takes comes out of a value with large $|u(i)|^2$ only, and a certain thing is shown. (8) Since the correlation output a (deltaf) shown by a formula is a vector sum of these loci, it becomes dominant influencing it of [in case size $|u(i)|^2$ of a sending-signal series takes a big value].

[0084]For this reason, at this embodiment, a reference frame sequence is expressed only by some typical vector.

[0085]Drawing 8 and drawing 9 showed an example when change of size $|u(i)|^2$ of a sending-signal series is small so that it might be easy to understand change of a vector locus. However, a time waveform of OFDM has the feature that change is comparatively large. Conversely, if it says, small cases of change are rare.

[0086]Drawing 11 is a figure showing an example of a vector locus at the time of transmitting data by which QPSK mapping was carried out. In drawing 11, it is several Ns=32 of a subcarrier which constitutes the point size N= 32 of FFT, and an OFDM signal. In the case of frequency-offset deltaf=0.4 given to a signal with which drawing 11 (a) is transmitted in a pilot symbol, drawing 11 (b) is a case of deltaf=0.9.

[0087]Distribution which takes a value with the zero neighborhood high [distribution of size $|u(i)|^2$ of a sending-signal series] and larger $|u(i)|^2$ than drawing 11 comes out only, and understands a certain thing.

[0088]At this embodiment, a reference frame sequence is expressed only by some typical vector. Hereafter, an example of a representative vector is explained using drawing 12 and drawing 13.

[0089]Drawing 12 is a figure showing a vector locus at the time of transmitting random data. Drawing 12 shows an example of several Ns=64 of a subcarrier which constitutes the point size N= 64 of FFT, and an OFDM signal, and frequency-offset deltaf=1.0. A vector which serves as a value with big size $|u(i)|^2$ of a sending-signal series also from drawing 12 comes out only, and understands a certain thing.

[0090]For this reason, at this embodiment, it expresses by a typical vector as shows drawing 13 a vector of drawing 12. That is, it expresses by a vector which made it 0 except a representative vector as shows drawing 13 a reference frame sequence.

[0091](The 1st example of composition of complex correlator), next an example of the complex correlators 31-33 shown in drawing 3 are explained. Drawing 14 is a block diagram showing the 1st example of composition of complex correlator. The complex correlator 50 of drawing 14 is provided with the following.

A number of stages is the shift register 51 of L.

Reference frame sequence 52.

The M complex multipliers 53.

The adding machine 54 adding an output of each complex multiplier 53.

[0092]The reference frame sequence 52 is a representative vector corresponding to a series number which takes a value with a big size in a segment of time of a signal transmitted in a pilot symbol. The multiplier 53 is arranged in a position corresponding to a number of a representative vector mentioned above. Drawing 14 shows an example in case numbers of L= 6 and a representative vector are 1, 4, and 6.

[0093](2nd example of composition of complex correlator) Drawing 15 is a block diagram showing the 2nd example of composition of complex correlator. The complex correlator 60 of drawing 15 is provided with the following.

The shift registers (the 2nd and 3rd signal shifting means) 61 and 62 in which both number of stageses are L.

The M complex multipliers 63.

The adding machine 64 adding an output of each complex multiplier 63.

The multiplier 63 is arranged at a position corresponding to a number of a representative vector mentioned above. Drawing 15 shows an example in case numbers of L= 6 and a representative vector are 1, 4, and 6.

[0094]Also in the complex correlator 60 of drawing 15, since the number of the multipliers 63 can be reduced, increase of circuit structure can be controlled and reduction of a manufacturing cost can be aimed at.

[0095]Drawing 16 is a block diagram showing a part of composition of OFDM receiver 11 which has the complex correlator 60 of drawing 15. OFDM receiver 11 of drawing 16 is provided with the following.

The sampling machine 19 which samples an OFDM reception signal.

1 symbol delay device (delay means) 65.

Complex correlator 60 of drawing 15.

[0096]In OFDM receiver 11 of drawing 16, a correlation peak of burst frame data in which two continuous pilot symbols have been arranged can be obtained with the complex correlator 60, By searching the maximum of a signal outputted from the complex correlator 60, a burst frame is detectable.

[0097](3rd example of composition of complex correlator) Although drawing 14 and drawing 15 which were mentioned above explained an example for which a size in a segment of time of a signal transmitted in a pilot symbol arranges a complex multiplier corresponding to a representative vector which takes a big value, As a signal transmitted in a pilot symbol, if a signal of a round series is transmitted, a complex multiplier can be arranged at equal intervals.

[0098]Hereafter, a known signal series which can arrange a complex multiplier at equal intervals is explained. This known signal series is transmitted to timing to which a pilot signal is transmitted.

[0099]In order to express reference frame sequence d_k by some representative vectors, a series set up so that phase arrangement in a frequency domain might go round to a subcarrier as a known signal series is adopted. Here, such a series is called a round series.

[0100]In a round series, when a repeating cycle is set to lg, a series {xk} of a time response which IFFT(ed) a known signal series {Xk} comes to have a value for every N/lg.

[0101]That is, by using a round series for a pilot symbol, the number of complex multipliers can be reduced and an increase in circuit structure can be suppressed as much as possible.

[0102]A round series is expressed with (9) types.

X_{k+1} and X_k^*=exp (jphi$_k$modulo l_g) -- (9)

However, k (k= 0, 1, --, N-1) is a subcarrier number, and phi$_i$ is a phase change between subcarriers.

[0103](9) Two or more series with which it is satisfied of a formula exist. However, in order that electric power may concentrate to a specific sample in a round series, from a point of PAPR (Peak to Average Power Ratio), it is disadvantageous. It is one of the faults of an OFDM modulation method that PAPR is large. From a viewpoint of power efficiency, the smaller possible one of PAPR is desirable.

[0104]For this reason, it is necessary to choose a round series by which equipartition of the electric power is carried out to each representative vector, i.e., a round series which serves as $|xi|^2$=N/Ig. Here, i shows a number of a representative vector and N shows a point size of FFT. Round cycle Ig is in agreement with the number of representative vectors. | There are (10) types as an example of a series used as $xi|^2$=N/Ig.

(phi 0, phi 1, phi 2, --, phi 15)

= (0, pi/2, -pi/2, pi, pi/2, -pi/2, pi, 0, pi, pi/2, pi/2, pi, -pi/2, -pi/2,0,0) -- (10)

Here, Ig=16 and Xk are taken as QPSK mapping.

[0105]In this series, an interval of a representative vector turns into regular intervals (i= 0, N/Ig, 2.N/Ig, --, -(Ig-1) N/Ig).

[0106]Drawing 17 is a block diagram showing the 3rd example of composition of complex correlator at the time of using a pilot signal of a round series. Since the time response has a value for every regular intervals when a round series is used for a known signal series, the multiplier 102 is arranged at equal intervals. Drawing 17 shows an example in case the number of multipliers is 4. The number of the multipliers 102 is in agreement with round cycle Ig. That is, by using a round series for a pilot symbol, the number of complex multipliers in slide correlator can be reduced, and an increase in circuit structure can be controlled.

[0107]Next, composition of complex correlator in a case of transmitting a pilot signal of a round series is explained.

[0108](4th example of composition of complex correlator) Drawing 18 is a block diagram showing the 4th example of composition of complex correlator. The complex correlator 70 of drawing 18 is provided with the following.

Both number of stageses are the shift registers 71 and 72 of L.

The M complex multipliers 73.

The adding machine 74 adding an output of each complex multiplier 73.

The multiplier 73 is arranged at a position corresponding to a number of a representative vector.

[0109]Since a pilot signal is a round series, as shown in drawing 18, it can arrange the multiplier 73 at equal intervals.

[0110]Complex correlator of drawing 18 is constituted like drawing 15 except arranging the multipliers 73 and 85 at equal intervals. Therefore, the same operation and effect as drawing 15 are acquired.

[0111](5th example of composition of complex correlator) Drawing 19 is a block diagram showing the 5th example of composition of complex correlator. The complex correlator 90 of drawing 19 is provided with the following.

The serial/parallel-conversion machine 91 which is the composition in a case of transmitting a pilot signal of a round series, and changes an input system sequence parallel at a rate of 1:K.

A number of stages is the shift register 92 of M.

The M complex multipliers 93.

The adding machine 94 adding an output of each complex multiplier 93, and the reference frame sequence 95.

The reference frame sequence 95 is a representative vector corresponding to a series number which takes a value with a big size in a segment of time of a signal transmitted in a pilot symbol.

[0112]The complex correlator 20 of drawing 19 is the point of performing a complex operation between a pilot signal and a reference frame sequence which were received, and differs from the complex correlator 20 of drawing 18. Also in the complex correlator 90 of drawing 19, a manufacturing cost is reducible while being able to control increase of circuit structure, since there are few multipliers and it ends.

[0113](Other examples of composition of a frequency error & timing error estimation machine) Drawing 20 is a block diagram showing other examples of composition of a frequency error & timing error estimation machine. A signal outputted from the sampling machine 19 shown in drawing 1 is inputted into the frequency error &

timing error estimation machine 20a of drawing 20. From the frequency error & timing error estimation machine 20a, a frequency error signal supplied to the local oscillator 18 and a timing error signal supplied to FFT21 are outputted.

[0114]The frequency error & timing error estimation machine 20a of drawing 20 is provided with the following.

Shift register 30.

Two or more complex correlators 31-33.

Maximum primary detecting element 34.

The comparator 111 and the average received power test section 112.

The reference frame sequences 37-39 different, respectively are set to each complex correlators 31-33. Each complex correlators 31-33 are provided with the following.

The complex multiplier 41 which multiplies a signal inputted from the shift register 30, and a reference frame sequence.

The adding machine 42 adding an output of the complex multiplier 41.

The reference frame sequences 37-39 set as the complex correlators 31-33 are the signals which gave a different frequency offset to a signal transmitted in a pilot symbol.

[0115]The maximum primary detecting element 34 detects the maximum of a correlation value outputted from each complex correlators 31-33, and outputs the maximum and frequency offset quantity at the time of a correlation value. An error of a carrier frequency is detectable from frequency corresponding to complex correlator which outputted the maximum. Frequency offset quantity obtained here is a discrete value depending on the number of complex correlator. For this reason, a frequency error is acquired with the interpolation using an output from complex correlator which outputted the maximum, and complex correlator contiguous to that complex correlator.

[0116]By detecting the maximum of each output signal of two or more complex correlators, a position of a known signal with a good autocorrelation characteristic included in an input signal can be detected, and, thereby, a synchronization of a burst frame can be established.

[0117]A correlation value and frequency offset quantity which were outputted from the maximum primary detecting element 34 are inputted into the comparator 111. An output signal of the average received power test section 112 is inputted into the comparator 111. A signal which the sampling machine 19 shown in drawing 1 outputs is inputted into the average received power test section 112, and an average received power value is outputted to it. The average received power test section 112 measures average power of an input signal. The comparator 111 sets up a compound value based on information on average power of an input signal, and performs a comparison operation of this compound value and the maximum of a correlation value outputted from the maximum primary detecting element 34.

[0118]By this comparison operation, the comparator 111 searches for an error of a position of a known signal with a good autocorrelation characteristic and an internal clock which are contained in an input signal, and outputs that error value as timing offset. Since average power becomes large so that an absolute value of a correlation output outputted from the complex correlators 31-33 is large, the comparator 111 of a graphic display outputs a frequency error signal and a correlation output maximum signal on the basis of a time of becoming beyond a compound value to which electric power measured by the average power test section 112 was set beforehand.

[0119]By composition like drawing 20, detection of a sampling timing error and a carrier frequency error is attained, and an OFDM signal receiving set in which a reliable signal transmission is possible can be realized.

[0120]Although an embodiment mentioned above explained an example which outputs a frequency error signal and a timing error signal from the maximum primary detecting element 36, only a frequency error signal is outputted and only error adjustment of a carrier frequency may be performed.

[0121]

[Effect of the Invention]The pilot signal which was received according to this invention as explained to details above, In order to control the frequency of a reproduced carrier signal based on the result of having performed complex correlation operation, between the reference signals with which a frequency offset which is different to a pilot signal, respectively was set up, The establishes synchronization of a reception frame can be performed promptly and it becomes a signal transmission with stable high reliability, and receivable [its]. Since the composition inside a complex correlation arithmetic means can be simplified, increase of circuit structure can be controlled and a manufacturing cost can be reduced in connection with it.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]

[Drawing 1]The block diagram of one embodiment of the OFDM signal communications system provided with the OFDM signal receiving set concerning this invention.

[Drawing 2]The figure showing the data configuration of the burst frame of the OFDM signal transmitted from an OFDM transmitter.

[Drawing 3]The block diagram showing the internal configuration of the frequency error & timing error estimation machine shown in drawing 1.

[Drawing 4]The figure showing the example of the correlation value sequence outputted from complex correlator.

[Drawing 5]The figure showing the series acquired by autocorrelation arithmetic.

[Drawing 6]The figure showing the reference frame sequence which gave frequency-offset deltaf to the signal transmitted in a pilot symbol, and the example of the frequency response of size $|a(\text{deltaf})|^2$ of the correlation output of an input signal.

[Drawing 7]The figure showing the vector showing a gap of frequency.

[Drawing 8]The figure showing an example of the vector locus in deltaf=0.25.

[Drawing 9]The figure showing an example of the vector locus in deltaf=0.5.

[Drawing 10]The figure showing size $|u(i)|^2$ of the sending-signal series corresponding to drawing 8 and drawing 9.

[Drawing 11]The figure showing the example of the vector locus at the time of transmitting the data by which QPSK mapping was carried out.

[Drawing 12]The figure showing the vector locus at the time of transmitting random data.

[Drawing 13]The figure showing the vector locus which made it 0 except the representative vector.

[Drawing 14]The block diagram showing the 1st example of composition of complex correlator.

[Drawing 15]The block diagram showing the 2nd example of composition of complex correlator.

[Drawing 16]The block diagram showing a part of composition of the OFDM receiver which has the complex correlator of drawing 15.

[Drawing 17]The block diagram showing the 3rd example of composition of the complex correlator at the time of using a round series for a pilot signal.

[Drawing 18]The block diagram showing the 4th example of composition of complex correlator.

[Drawing 19]The block diagram showing the 5th example of composition of complex correlator.

[Drawing 20]The block diagram showing other examples of composition of a frequency error & timing error estimation machine.

[Drawing 21]The block diagram showing the composition of the OFDM modulation device used for the transmitting side.

[Drawing 22]The figure explaining guard intervals.

[Drawing 23]The block diagram showing the composition of the OFDM demodulator used for a receiver.

[Drawing 24]The figure showing frequency-offset detection / removal method indicated in literature.

[Description of Notations]

10 OFDM transmitter

11 OFDM receiver

12 Reverse fast Fourier transformation equipment (IFFT)

13 and 17 Frequency converter

14 and 18 Local oscillator

15 and 16 Antenna

19 Sampling machine

20 Timing error estimation machine

21 Fast Fourier transformation equipment (FFT)

30 and 35 Shift register

31-33 Complex correlator

34 and 36 Maximum primary detecting element

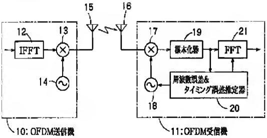
37-39 Reference frame sequence

40 Complex multiplier

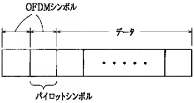
41 Adding machine

DRAWINGS

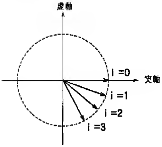
[Drawing 1]


15
16
12
IFFT
13
14
17
19
標本化器
21
FFT
周波数誤差&
タイミング誤差推定器
18
20
10: OFDM送信機
11:OFDM受信機

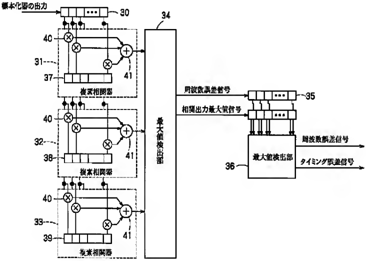
[Drawing 2]


OFDMシンボル
データ
パイロットシンボル

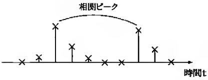
[Drawing 7]


虚軸
i =0
実軸
i =1
i =2
i =3

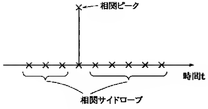
[Drawing 3]


標本化器の出力
30
34
40
31
37
41
複素相関器
40
32
38
41
複素相関器
40
33
39
41
複素相関器
最大値検出部
周波数誤差信号
相関出力最大値信号
35
周波数誤差信号
最大値検出部
タイミング誤差信号
36

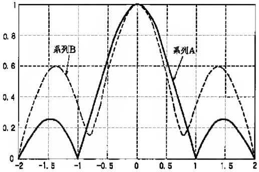
[Drawing 4]



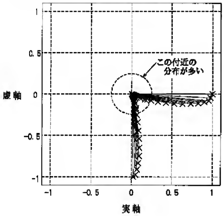
[Drawing 5]


相関ピーク
時間t
相関サイドローブ

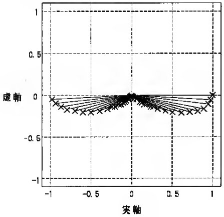
[Drawing 6]



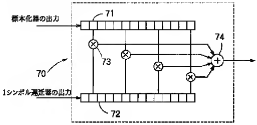
[Drawing 8]



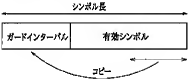
[Drawing 9]



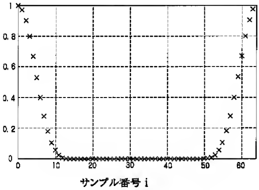
[Drawing 18]


標本化器の出力
71
74
73
70
1シンボル遅延器の出力
72

[Drawing 22]

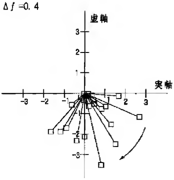

シンボル長
ガードインターバル
有効シンボル
コピー

[Drawing 10]

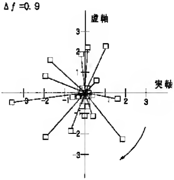


[Drawing 11]

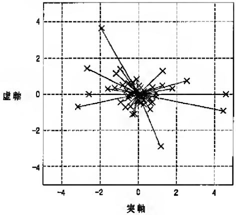
(a) Δf =0.4



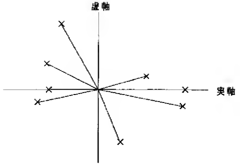
(b) Δf =0.9



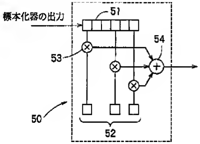
[Drawing 12]



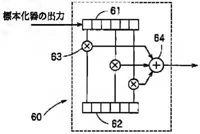
[Drawing 13]



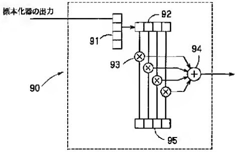
[Drawing 14]


標本化器の出力
51
54
53
50
52

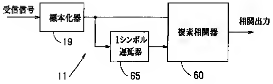
[Drawing 15]


標本化器の出力
61
64
63
60
62

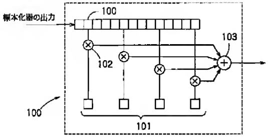
[Drawing 19]


標本化器の出力
92
91
94
93
90
95

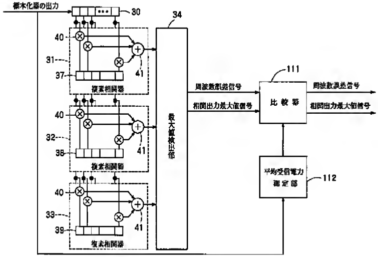
[Drawing 16]


受信信号
標本化器
19
11
1シンボル
遅延器
65
複素相関器
60
相関出力

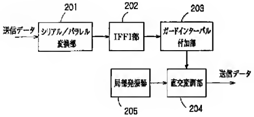
[Drawing 17]


標本化器の出力
100
103
102
100
101

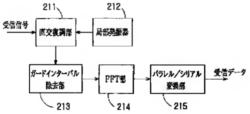
[Drawing 20]


標本化器の出力
30
34
40
31
37
41
複素相関器
40
32
38
41
複素相関器
40
33
39
41
複素相関器
最大値検出部
周波数誤差信号
相関出力最大値信号
111
比較器
周波数誤差信号
相関出力最大値信号
平均受信電力測定部
112

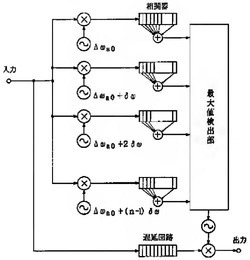
[Drawing 21]


201
202
203
送信データ
シリアル／パラレル変換部
IFFI部
ガードインターバル付加部
局部発振器
直交変調部
送信データ
205
204

[Drawing 23]


211
212
受信信号
直交復調部
局部発振器
ガードインターバル除去部
FFT部
パラレル/シリアル変換部
受信データ
213
214
215

[Drawing 24]


相関器
入力
$\Delta\omega_{a0}$
$\Delta\omega_{a0}+\delta\omega$
$\Delta\omega_{a0}+2\delta\omega$
$\Delta\omega_{a0}+(n-1)\delta\omega$
最大値検出部
遅延回路
出力